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PERFORMANCE EVALUATION OF TWO PROTOTYPE BEVERAGE CHILLERS IN A FIELD ENVIRONMENT

by
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and
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Natick, Massachusetts 01760-5018

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14. ABSTRACT

Two evaporative beverage chiller prototypes were tested against a control for performance, water temperature perception and overall hydration. Thirty-four Marines were separated into three groups for this 6-day between-groups test. Each group tested one of the three conditions (battery powered, non-powered, or control: hydration system with neither chiller) for a period of 2 days. After 2 days, each group rotated to a different condition. Each group consisted of approximately 10 Marines. The three conditions were counter balanced to control for order effects. The average number of hydrations bags consumed per Marine per day increased from 1.1 to 1.6, an increase of approximately 1.5 L of water. Most Marines reported overall satisfaction with the prototypes aside from some design flaws that made them either too large or too easily broken.

15. SUBJECT TERMS

ARMY	HOT REGIONS	WATER SUPPLIES	HIGH TEMPERATURE
WATER	NONELECTRIC	POTABLE WATER	PORTABLE EQUIPMENT
COOLING	HOT WEATHER	WATER CHILLERS	TEST AND EVALUATION
CHILLING	CONSUMPTION	DRINKING WATER	REFRIGERATION SYSTEMS
BEVERAGES	BATTLEFIELDS	ARMY PERSONNEL	
HYDRATION	CHILLER UNITS	ICE(INDIVIDUAL COOLING EQUIPMENT)	
PROTOTYPES	WATER COOLING	COOLING AND VENTILATING EQUIPMENT	

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1 INTRODUCTION

According to research by the United States Army Research Institute for Environmental Medicine (USARIEM) [1], Soldiers must drink up to 3 gal of water per day to stay hydrated. However, studies have shown that soldiers drink less than they should when water is unpalatably warm (~100 ºF) [2]. This leads to dehydration, heat stroke, and other related injuries. To solve this problem, two beverage chiller prototypes, battery-powered and non-powered, were developed by the Natick Soldier Research, Development and Engineering Center (NSRDEC) that provide soldiers with cool, palatable beverages on-demand, anywhere on the battlefield.

This report documents testing by actual warfighters of both prototypes against a control for performance, water temperature perception, and overall hydration. The control used was a typical hydration system with neither water chiller. The testing was conducted by NSRDEC in a desert environment at the Twentynine Palms Marine Training Facility, Camp Wilson, CA, from September 6 to 11, 2010. The participants were 34 Marines who were separated into three groups. Each group tested one of the three systems (the two prototypes and the control system) for 2 days, and then rotated to a different unit for another 2 days of testing. Thus, each system was tested for 6 days by 34 Marines. The testing was designed so that each Marine would indicate a response for each test condition on each day of testing, i.e., two test responses per Marine per test condition for each system. The three test systems were counter balanced to control for order effects.

Both prototypes rely on the evaporation of water to the atmosphere to chill the drinking water. One wicks some of the drinking water onto a fabric that surrounds a water cavity and relies on air currents for natural convection (Figure 1), and the other evaporates the drinking water through a semi-permeable membrane using forced convection via a small computer fan.

Figure 1: Prototype Beverage Chillers. Left: Non-Powered; Right: Battery-Powered

The minimal temperature that can be reached by evaporating water into the atmosphere is called the wet bulb temperature, and it is dependent on the relative humidity in the air. The systems work best in dry, arid climates, so they are only useful for desert missions.

Section 2 documents the demographics of the 34 Marines who participated in the testing. Section 3 presents the results from the testing of the control

hydration system. Section 4 presents the results from the testing of the battery-powered water chiller. Section 5 presents the results from the testing of the non-powered water chiller. Section 6 discusses the preferences reported and compares the results from the testing of the three systems. Section 7 presents quotations from the participants on the reasons for their system preferences and their likes and dislikes of the two chiller prototypes. Section 8 draws conclusions from the test results.

2 PARTICIPANT DEMOGRAPHICS

Over 90% (31) of the 34 Marines who participated in this data collection were male. All but two participants were Enlisted (most of whom were E-3s and E-4s), with one Warrant Officer (W-2) and one Officer (O-6). Just over one-half (18) of the participants were between 19 and 21 years of age, nearly one-quarter (8) of them were between 22 and 26, and nearly one-quarter (8) were between the ages of 27 and 49.

2.1 PRIMARY MILITARY OCCUPATIONAL SPECIALITY (MOS)

Approximately one-quarter (26.5%, n=9) of the respondents' primary Military Occupational Specialty (MOS) was Ammunition Technician, one-fifth (20.6%, n=7) was Transportation, 14.7% (n=5) was Supply, and 8.8% (n=3) was Engineer, Of the remaining respondents, two (5.9%) each had the primary MOS Infantry, Aviation Mechanics, and Artillery, and there was one Tank Mechanic, one Senior Enlisted Advisor, one Hazmat Technician, and one Air Traffic Control Radar Technician. See Table 1.

Table 8: Primary MOS

Primary MOS	%	*n*
Ammo Tech	26.5	*9*
Transportation	20.6	*7*
Supply	14.7	*5*
Engineer	8.8	*3*
Infantry	5.9	*2*
Aviation Mechanic	5.9	*2*
Artillery	5.9	*2*
Tank Mechanic	2.9	*1*
Senior Enlisted Advisor	2.9	*1*
Hazmat Tech	2.9	*1*
Air Traffic Control Radar Tech	2.9	*1*

2.2 YEARS OF SERVICE

The average years of service was 6 years, with a range of 1-27 years. As shown in Table 2, 70.1% (n=24) of respondents had served for 1-3 years, 8.8% (n=3) for 4-6 years, 11.8% (n=4) for 11-17 years, and the remaining 8.8% (n=3) for 24-27 years.

Table 9: Years of Service

Years of Service	%	*n*
1-3	70.1	*24*
4-6	8.8	*3*
7-10	0	*0*
11-17	11.8	*4*
24-27	8.8	*3*

2.3 DEPLOYMENT

Thirteen (38%) of the participants had never been deployed, while 21 (62%) of them had been deployed for an average of 1 year, with a range of 3 months to 3 years.

2.4 HYDRATION SYSTEM EXPERIENCE

Every participant had used a hydration system previous to this evaluation.

2.5 ESTIMATED DAILY WATER CONSUMPTION

Most of the respondents (85.3%, n=29) estimated that they drank an average of one to three full hydration bags of water a day. Two Marines reported drinking less than one hydration bag in a day, two reported drinking four in a day, and one reported drinking six or more as a daily average. See Table 3.

Table 10: Estimated Daily Water Consumption

Number of Full Hydration Bags	%	*n*
< 1	5.9	*2*
1	14.7	*5*
2	50.0	*17*
3	20.6	*7*
4	5.9	*2*
5	0	*0*
≥ 6	2.9	*1*

The estimated average consumption of full hydration bags for the entire group was *2.2 per Marine per day* (when counting *< 1* as *0.5* and *≥ 6* as *6.5*).

2.6 WATER BLOW BACK BEHAVIOR

Most of respondents (70.6%, n=24) reported that they *do not* blow water back through their hydration hose, while 14.7%, n=5, reported that they *do* blow water back, with an equal number (14.7%, n=5) reporting that they do not know what this behavior is.

3 CONTROL HYDRATION SYSTEM RESULTS

The data presented in this section are aggregates for all three groups combined solely for the control hydration system, with neither water chiller. Each of the 34 Marines was instructed to indicate a response on each day of testing for each test condition. Therefore, there are a possible two data points from each Marine (68 total data points) for each condition in this section, but not all of the Marines responded for each condition on both days (i.e., *total n = < 68* in each table).

3.1 MAJOR ACTIVITY

Table 4 displays the daily behavior that best characterized each Marine's major activity while using the hydration bag.

Table 11: Major Activity – Control

"Today I was mostly…"	%	*n*
On foot	40.7	*22*
Standing/sitting outside	37.0	*20*
In a vehicle *with* air conditioning	0	*0*
In a vehicle with *no* air conditioning	5.6	*3*
Indoors	16.7	*9*

The majority of Marines were either on foot (40.7%) or were standing/sitting outside (37.0%) while evaluating the control unit. Only 5.6% were in a vehicle with *no* air conditioning, and 16.7% spent most of the day indoors. No one was in a vehicle *with* air conditioning.

3.2 PHYSICAL EXERTION

Table 5 displays an aggregate of the reported degree of physical exertion for the control unit.

Table 12: Physical Exertion – Control

Physical Exertion	%	*n*
None at all	3.6	*2*
Slight exertion	35.7	*20*
Moderate exertion	44.6	*24*
A great deal of exertion	16.1	*9*
Extreme exertion	0	*0*

The largest percentage of Marines (44.6%) reported a *moderate* degree of exertion while using the control unit, followed by 35.7% reporting *slight* exertion, 16.1% reporting a *great deal* of exertion, and 3.6% reporting *no* exertion at all. None reported extreme exertion.

3.3 DAILY WATER CONSUMPTION

Table 6 displays the aggregate daily water consumption for the control system by the number of full hydration bags reported consumed by the respondents .

Table 13: Daily Water Consumption – Control

Number of Full Hydration Bags	%	*n*
< 1	30.4	*17*
1	41.1	*23*
2	21.4	*12*
3	1.8	*1*
4	5.4	*3*
5	0	*0*
≥ 6	0	*0*

The largest percentage of Marines (41.1%) reported drinking *one* full hydration bag per day , followed by 30.4% reporting *less than one* per day, and 21.4% reporting *two* per day. One Marine reported drinking an average of *three* per day (1.8%), while three Marines reported an average of *four* per day (5.4%). No one reported drinking *five* or *six or more* per day.

The reported average consumption of full hydration bags for the entire group was *1.1 per Marine per day* using the control unit (when counting *< 1* as *0.5*). This is one-half of the estimated average (*calculated the same way*).

The Marines may have over-estimated their average consumption, or may have been drinking less water than usual during this evaluation, or a combination thereof. For consistency and internal reliability, the *actual group average* collected from the control data (*1.1 per Marine per day*) was used to compare the powered water chiller and the non-powered water chiller group average, rather than the *estimated group average* projected by Marines before the evaluation began.

3.4 WATER TEMPERATURE SATISFACTION/DISSATISFACTION RATINGS

Table 7 displays satisfaction/dissatisfaction ratings for the control unit.

Table 14: Water Temperature Satisfaction – Control

Degree of Satisfaction/Dissatisfaction	%	*n*
Extremely satisfied	0	*0*
Moderately satisfied	5.4	*3*
Slightly satisfied	8.9	*5*
Neither satisfied nor dissatisfied	30.4	*17*
Slightly dissatisfied	12.5	*7*
Moderately dissatisfied	32.1	*18*
Extremely dissatisfied	10.7	*6*

Over one-half of the respondents (55.3%) indicated a measure of *dissatisfaction*, while only 14.3% indicated a measure of *satisfaction*, and nearly one-third (30.4%) reported indifference.

3.5 SENSORY MEASURES OF WATER TEMPERATURE

Table 8 displays self-report ratings for perception of the water temperature for the control system.

Table 15: Water Temperature Perception – Control

Degree of Warmth/Coldness	%	*n*
Extremely warm	7.1	*4*
Moderately warm	50.0	*28*
Slightly warm	17.9	*10*
Neither warm nor cold	17.9	*10*
Slightly cold	3.6	*2*
Moderately cold	3.6	*2*
Extremely cold	0	*0*

A measure of warmth was reported by 75% of the group, with 50% expressing the water from their hydration bag was *moderately warm*, 7.1% indicating *extremely warm*, 17.9% indicating *slightly warm*, and 17.9% indicating *neither warm nor cold*. Two Marines (3.6%) found their water to be *slightly cold*, and two others (3.6%) found it to be *moderately cold.* None found their water to be *extremely cold*.

3.6 HYDRATION SYSTEM BODY LOCATION

All but five of the respondents (91.1%) wore their hydration systems on their backs during the entire test. The locations used by those five respondents are listed in Table 9.

Table 16: Donned Location – Control

Location	%	*n*
Hanging on truck	1.8	*1*
I carried it and wore it on my back.	1.8	*1*
I carried it most of the time.	1.8	*1*
Left in the shade, water got too hot to drink when I carried it on my back	1.8	*1*
Left it on the floor in the shade	1.8	*1*

4 BATTERY-POWERED WATER CHILLER RESULTS

The data presented in this section are aggregates for all three groups combined solely for the battery-powered water chiller. Each of the 34 Marines was instructed to indicate a response on each day of testing for each test condition. Therefore, there are a possible two data points from each Marine (68 total data points) for each condition in this section, but not all of the Marines responded for each condition on both days (i.e., *total n = < 68* in each table).

4.1 MAJOR ACTIVITY

Table 10 displays the daily behavior that best characterized each Marine's major activity while using the battery-powered water chiller:

Table 17: Major Activity – Powered

"Today I was mostly…"	%	*n*
On foot	31.1	*19*
Standing/sitting outside	49.2	*30*
In a vehicle *with* air conditioning	3.3	*2*
In a vehicle with *no* air conditioning	1.6	*1*
Indoors	14.8	*9*

The majority of Marines were either on foot (31.1%) or standing/sitting outside (49.2%) while evaluating the battery powered water chiller. 3.3% were in a vehicle with air conditioning, 1.6% were in a vehicle with *no* air conditioning, while 14.8% were indoors.

4.2 PHYSICAL EXERTION

Table 11 displays an aggregate of the reported degree of physical exertion while using the powered chiller.

Table 18: Physical Exertion – Powered

Physical Exertion	%	*n*
None at all	9.5	*6*
Slight exertion	31.7	*20*
Moderate exertion	46.0	*29*
A great deal of exertion	12.7	*8*
Extreme exertion	0	*0*

The largest percentage of the Marines (46.0%) reported a *moderate* degree of exertion while using the battery-powered water chiller, followed by 31.7% reporting *slight* exertion, 12.7% reporting a *great deal* of exertion, and 9.5% reporting none at all. None reported extreme exertion.

4.3 DAILY WATER CONSUMPTION

Table 12 displays the aggregate daily water consumption for the battery-powered water chiller by the number of full hydration bags reported consumed by the respondents.

Table 19: Daily Water Consumption – Powered

Number of Full Hydration Bags	%	*n*
< 1	20.6	*13*
1	33.3	*21*
2	28.6	*18*
3	14.3	*9*
4	3.2	*2*
5	0	*0*
≥ 6	0	*0*

One-third of the Marines reported drinking *one* full hydration bag of water per day, followed by 28.6% reporting *two* per day, 20.6% reporting *less than one* per day, and 14.3% reporting *three* per day. Two Marines (3.2%) reported drinking an average of *four* per day. None reported drinking *five* or *six or more* per day.

The reported average consumption of full hydration bags for the entire group was *1.6 per Marine per day* for the battery-powered water chiller (when counting *< 1* as *0.5*).

4.4 WATER TEMPERATURE SATISFACTION/DISSATISFACTION RATINGS

Table 13 displays satisfaction/dissatisfaction ratings for the battery-powered water chiller.

Table 20: Water Temperature Satisfaction – Powered

Degree of Satisfaction/Dissatisfaction	%	*n*
Extremely satisfied	0	*0*
Moderately satisfied	20.6	*13*
Slightly satisfied	42.9	*27*
Neither satisfied nor dissatisfied	9.5	*6*
Slightly dissatisfied	15.9	*10*
Moderately dissatisfied	4.8	*3*
Extremely dissatisfied	6.3	*4*

Over one-half of the respondents (63.5%) indicated a measure of *satisfaction*, 27.0% indicated a measure of *dissatisfaction*, and 9.5% reported indifference.

4.5 SENSORY MEASURES OF WATER TEMPERATURE

Table 14 displays self-report ratings for perception of the water temperature for the powered chiller.

Table 21: Water Temperature Perception – Powered

Degree of Warmth/Coldness	%	*n*
Extremely warm	0	*0*
Moderately warm	9.5	*6*
Slightly warm	4.8	*3*
Neither warm nor cold	12.7	*8*
Slightly cold	42.9	*27*
Moderately cold	30.2	*19*
Extremely cold	0	*0*

Nearly three-quarters (73.1%) of the respondents indicated a measure of coldness while only 14.3% of the group indicated a measure of warmth, with 12.7% expressing indifference. None found their water to be *extremely cold* or *extremely warm*.

4.6 PERFORMANCE

Table 15 displays satisfaction/dissatisfaction ratings for performance of the battery-powered water chiller.

Table 22: Performance – Powered

Degree of Satisfaction/Dissatisfaction	%	*n*
Extremely satisfied	1.6	*1*
Moderately satisfied	14.3	*9*
Slightly satisfied	30.2	*19*
Neither satisfied nor dissatisfied	17.5	*11*
Slightly dissatisfied	19.0	*12*
Moderately dissatisfied	11.1	*7*
Extremely dissatisfied	6.3	*4*

Nearly one-half (46.1%) of the respondents expressed a degree of satisfaction, 36.4% expressed a degree of dissatisfaction, and 17.5% expressed indifference.

4.7 EASE OF USE

Table 16 displays ease/difficulty of use ratings for the battery-powered water chiller.

Table 23: Ease of Use – Powered

Ease/Difficulty of Use	%	*n*
Very easy	27.4	*17*
Moderately easy	25.8	*16*
Slightly easy	19.4	*12*
Neither easy nor difficult	16.1	*10*
Slightly difficult	6.5	*4*
Moderately difficult	1.6	*1*
Very difficult	3.2	*2*

Nearly three-quarters (72.6%%) of the respondents expressed a degree of ease, only 11.3% expressed a degree of difficulty, and 16.1% expressed indifference

4.8 HYDRATION SYSTEM BODY LOCATION

Almost all (97.8%) of the respondents wore their hydration systems on their backs for the entire test while one participant reported using the adaptor to relocate the battery-powered water chiller away from the water cap for ease of refilling.

4.9 FREQUENCY OF CLEANING

Table 17 displays the daily frequency at which dust was clapped out of the battery-powered water chiller.

Table 24: Frequency of Cleaning - Powered

Number of times dust clapped out of unit per day	%	*n*
0	85.7%	*54*
1	6.3	*4*
2	1.6	*1*
3	4.8	*3*
4	0	*0*
≥ 5	1.6	*1*

Most (85.7%) of respondents *never* clapped dust out of their battery-powered water chillers.

4.10 EASE OF CLEANING

Table 18 displays the ease or difficulty with which dust was clapped out of the battery-powered water chiller.

Table 25: Ease of Cleaning – Powered

Ease/Difficulty of Dust Clapping	%	*n*
Never clapped dust out	73.0	*46*
Very easy	3.2	*2*
Moderately easy	4.8	*3*
Slightly easy	3.2	*2*
Neither easy nor difficult	11.1	*7*
Slightly difficult	3.2	*2*
Moderately difficult	0	*0*
Very difficult	1.6	*1*

Though, again, the majority responded that they did not clap dust out of their battery-powered water chillers, the response was only 73.0% compared with the 85.7% who responded that they clapped zero times per day to the frequency question. For those who did clap dust, an equal number (11.1% of total respondents) expressed a degree of ease and expressed indifference, and a smaller number (4.8% of total respondents) expressed a degree of difficulty. Some Marines who responded they clapped dust "zero times per day" to the frequency question may have selected "neither easy nor difficult" instead of "never clapped dust out", which would explain most of the discrepancy (seven of the eight who responded differently).

4.11 BATTERY-POWERED WATER CHILLER OVERALL SATISFACTION

Table 19 displays overall satisfaction/dissatisfaction ratings for performance of the battery-powered water chiller. Less than one-half (43.0 %) expressed a degree of satisfaction, slightly fewer (34.8%) expressed a degree of dissatisfaction, and 22.2% expressed indifference.

Table 26: Overall Satisfaction – Powered

Degree of Satisfaction/Dissatisfaction	%	*n*
Extremely satisfied	1.6	*1*
Moderately satisfied	11.1	*7*
Slightly satisfied	30.2	*19*
Neither satisfied nor dissatisfied	22.2	*14*
Slightly dissatisfied	19.0	*12*
Moderately dissatisfied	9.5	*6*
Extremely dissatisfied	6.3	*4*

5 NON-POWERED WATER CHILLER RESULTS

The data presented in this section are aggregates for all three groups combined solely for the non-powered water chiller. Each of the 34 Marines was instructed to indicate a response on each day of testing for each test condition. Therefore, there are a possible two data points from each Marine (68 total data points) for each condition in this section, but not all of the Marines responded for each condition on both days (i.e., *total n = < 68* in each table).

5.1 MAJOR ACTIVITY

Table 20 displays the behavior that best characterized each Marine's major activity each day while using the non-powered water chiller:

Table 27: Major Activity – Non-Powered

"Today I was mostly…"	%	*n*
On foot	37.9	*22*
Standing/sitting outside	32.8	*19*
In a vehicle *with* air conditioning	3.4	*2*
In a vehicle with *no* air conditioning	8.6	*5*
Indoors	17.2	*10*

The majority of the Marines were either on foot (37.9%) or standing/sitting outside (32.8%) while evaluating the non-powered water chiller. Only 3.4% were in a vehicle with air conditioning, 8.6% were in a vehicle with *no* air conditioning, and 17.2% were indoors.

5.2 PHYSICAL EXERTION

Table 21 displays an aggregate of the reported degree of physical exertion for the non-powered water chiller:

Table 28: Physical Exertion – Non-powered

Physical Exertion	%	*n*
None at all	9.8	*6*
Slight exertion	24.6	*15*
Moderate exertion	54.1	*33*
A great deal of exertion	9.8	*6*
Extreme exertion	1.6	*1*

The majority of the Marines (54.1%) reported a *moderate* degree of exertion while using the non-powered water chiller, followed by 24.6% reporting *slight* exertion, 9.8% reporting a *great deal* of exertion, 9.8% reporting *none at all*, and one Marine reporting *extreme* exertion.

5.3 DAILY WATER CONSUMPTION

Table 22 displays the aggregate daily water consumption for the non-powered water chiller by the number of full hydration bags reported consumed by the respondents.

Table 29: Daily Water Consumption – Non-Powered

Number of Full Hydration Bags	%	*n*
< 1	21.0	*13*
1	29.0	*18*
2	37.1	*23*
3	8.1	*5*
4	4.8	*3*
5	0	*0*
≥ 6	0	*0*

More than one-third (37.1%) of the of Marines reported drinking *two* full hydration bags of water per day, followed by 29.0% reporting *one* per day, 21.0% reporting *less than one* per day, 8.1% reporting *three* per day, and 4.8% reporting *four* per day. None reported drinking *five* or *six or more* per day.

The reported average consumption of full hydration bags for the entire group was *1.6 per Marine per day* for the non-powered water chiller (when counting *< 1* as *0.5*).

5.4 WATER TEMPERATURE SATISFACTION/DISSATISFACTION RATINGS

Table 23 displays satisfaction/dissatisfaction ratings for the non-powered water chiller.

Table 30: Water Temperature Satisfaction – Non-Powered

Degree of Satisfaction/Dissatisfaction	%	*n*
Extremely satisfied	22.6	*14*
Moderately satisfied	40.3	*25*
Slightly satisfied	22.6	*14*
Neither satisfied nor dissatisfied	1.6	*1*
Slightly dissatisfied	11.3	*7*
Moderately dissatisfied	0	*0*
Extremely dissatisfied	1.6	*1*

Most (85.5%) of the respondents indicated a measure of *satisfaction*, 12.9% indicated a measure of *dissatisfaction*, and 1.6% reported indifference.

5.5 SENSORY MEASURES OF WATER TEMPERATURE

Table 24 displays self-report ratings for perception of the water temperature for the non-powered water chiller.

Table 31: Water Temperature Perception – Non-powered

Degree of Warmth/Coldness	%	*n*
Extremely warm	0	*0*
Moderately warm	0	*0*
Slightly warm	0	*0*
Neither warm nor cold	6.5	*4*
Slightly cold	22.6	*14*
Moderately cold	62.9	*39*
Extremely cold	8.1	*5*

Most (93.5%) of the respondents indicated a measure of coldness, with the other 6.5% expressing indifference. There were no reports of any degree of warmth.

5.6 PERFORMANCE

Table 25 displays satisfaction/dissatisfaction ratings for performance of the non-powered water chiller.

Table 32: Performance – Non-Powered

Degree of Satisfaction/Dissatisfaction	%	*n*
Extremely satisfied	22.6	*14*
Moderately satisfied	37.1	*23*
Slightly satisfied	14.5	*9*
Neither satisfied nor dissatisfied	1.6	*1*
Slightly dissatisfied	17.7	*11*
Moderately dissatisfied	3.2	*2*
Extremely dissatisfied	3.2	*2*

Nearly three-quarters (74.3%) of the respondents expressed a degree of satisfaction, 24.1% expressed a degree of dissatisfaction, and 1.6% expressed indifference.

5.7 EASE OF USE

Table 26 displays ease/difficulty of use ratings for the non-powered water chiller.

Table 33: Ease of Use – Non-powered

Ease/Difficulty of Use	%	*N*
Very easy	48.4	*30*
Moderately easy	17.7	*11*
Slightly easy	9.7	*6*
Neither easy nor difficult	8.1	*5*
Slightly difficult	6.5	*4*
Moderately difficult	6.5	*4*
Very difficult	3.2	*2*

Approximately three-quarters (75.8%) of the respondents expressed a degree of ease, only 16.2% expressed a degree of difficulty, and 8.1% expressed indifference.

5.8 HYDRATION SYSTEM BODY LOCATION

All of the respondents wore their non-powered water chillers at the top of their hydration systems, on their backs. This is where they were originally attached previous to being issued to each participant.

5.9 FREQUENCY OF CLEANING

Table 27 displays the frequency at which dust was clapped out of the non-powered water chiller per day.

Table 34: Frequency of Cleaning – Non-Powered

Number of times dust clapped out of unit per day	%	*n*
0	88.7	*55*
1	8.1	*5*
2	1.6	*1*
3	1.6	*1*
4	0	*0*
$\geq$ 5	0	*0*

Most (88.7%) of the respondents *never* clapped dust out of their non-powered water chillers.

5.10 EASE OF CLEANING

Table 28 displays the ease/difficulty with which dust was clapped out of the non-powered water chiller.

Table 35: Ease of Cleaning – Non-Powered

Ease/Difficulty of Dust Clapping	%	*n*
Never clapped dust out	79.1	*49*
Very easy	0	*0*
Moderately easy	0	*0*
Slightly easy	3.2	*2*
Neither easy nor difficult	9.7	*6*
Slightly difficult	6.5	*4*
Moderately difficult	1.6	*1*
Very difficult	0	*0*

Though, again, the majority (79.1%) did not clap dust out of their non-powered water chillers, the response was only 79.1% compared with the 88.7% who responded that they clapped zero times per day to the frequency question. Only 3.2% expressed a degree of ease, 9.7% expressed indifference, and 8.1% expressed a degree of difficulty. Some Marines who responded they clapped dust "zero times per day" to the frequency question may have selected "neither easy nor difficult" instead of "never clapped dust out", which would explain the discrepancy.

5.11 NON-POWERED WATER CHILLER OVERALL SATISFACTION

Table 29 displays overall satisfaction/dissatisfaction ratings for the performance of the non-powered water chiller.

Table 36: Overall Satisfaction – Non-Powered

Degree of Satisfaction/Dissatisfaction	%	*n*
Extremely satisfied	25.8	*16*
Moderately satisfied	32.3	*20*
Slightly satisfied	12.9	*8*
Neither satisfied nor dissatisfied	6.5	*4*
Slightly dissatisfied	14.5	*9*
Moderately dissatisfied	4.8	*3*
Extremely dissatisfied	3.2	*2*

The majority of the respondents (71.0%) expressed a degree of satisfaction, 22.5% expressed a degree of dissatisfaction, and 6.5% expressed indifference.

6 DISCUSSION OF RESULTS

6.1 PREFERENCES

Only 20.7% (n=7) of participants prefer the battery-powered water chiller, while 69.0% (n=24) preferred the non-powered water chiller. One participant preferred both chillers equally over the control hydration system with neither chiller, and two preferred the control system.

6.2 WATER CONSUMPTION ESTIMATES IN RETROSPECT

After the data collection, the Marines were asked to estimate their water consumption habits throughout the evaluation for each of the three systems. Only 30 of the 34 participants responded to this request for each of the chillers, and only 29 of them responded for the control system. The responses are summarized in Table 30.

Table 37: Comparison of Actual and Estimated Water Consumption – All Three systems

	Much Less than Usual	Less than Usual	About the Same as Usual	More than Usual	Much More than Usual
Battery-Powered	0% n=0	40.0% n=12	33.3% n=10	26.7% n=8	0% n=0
Non-Powered	0% n=0	13.3% n=4	33.3% n=10	40.0% n=12	13.3% n=4
Control (Neither)	10.3% n=3	34.5% n=10	48.3% n=14	3.4% n=1	3.4% n=1

The non-powered water chiller had the highest attribution of water consumption, with 53.4% reporting a measure of *increased* consumption. Only 13.3% reported a *decrease* in water consumption, and 33.3% reported drinking about the same. More than one-quarter (26.7%) reported drinking *more* water than usual from the battery-powered water chiller, 40.0% reported drinking *less*, and 33.3% reported drinking about the same amount. For the control system, 48.3% reported drinking about the same amount as usual, and nearly the same number (44.8%) reported drinking *less* water. Only two Marines reported drinking *more* water.

6.3 WATER CONSUMPTION COMPARISONS

The actual group average of full hydration bags consumed *per Marine per day* from the control system was only 1.1, compared to 1.6 from each water chiller. These figures suggest there was an average increase in water consumption of almost 50% per day per Marine when using either the battery-powered water chiller or the non-powered water chiller instead of the control system.

However, it is important to highlight that the 44.8% *decrease from usual consumption* reported by the Marines when they drank water from the control system (shown in Table 30 and discussed in Section 6.2) mirrors the 50% decrease from the pre-test estimated consumption to the actual water consumption cited in Section 3 (from an estimated average of 2.2 full hydration bags per day to an average of only 1.1 full hydration bags actually consumed per day). Therefore, when looking at the reported *decrease* in water consumption for both water chillers, it must be compared to the control's relative decrease as well. The decrease in water consumption was *less* for both chillers than for the control system. Thus, these comparisons show a relative increase in water consumption habits for both water chillers over the control. However, the battery-powered water chiller's decrease was only 4.8% *less* than the control's decrease while the non-powered water chiller's decrease was 31.5% *less* than the control's decrease, indicating a much larger relative increase in consumption with the non-powered chiller than with the battery-powered chiller.

6.4 WATER TEMPERATURE SATISFACTION COMPARISONS

Table 31 displays collapsed averages for water temperature satisfaction/dissatisfaction for all three conditions. (Here, dissatisfaction spans the range of extremely, moderately, and slightly dissatisfied while satisfaction spans the range of extremely, moderately, and slightly satisfied).

Table 38: Water Temperature Satisfaction **Comparisons**

	Dissatisfaction %	Indifference %	Satisfaction %
Control	55.3	30.4	14.3
Battery-powered	20.7	9.5	63.5
Non-powered	12.9	1.6	85.5

The control system (ambient water temperature) had the highest percentage of dissatisfaction (55.3%) and indifference (30.4%) and the lowest percentage of satisfaction (14.3%). The battery-powered water chiller showed an improvement over the control system, with a lower percentage of dissatisfaction (20.7%), lower indifference (9.5%), and higher satisfaction (63.5%). The non-powered water chiller showed even greater improvement, with the lowest percentage of dissatisfaction (12.9%), the lowest indifference (1.6%) and the highest satisfaction (85.5%).

6.5 HYDRATION BAG BODY LOCATION COMPARISONS

Although most of the Marines (91.1%), reported wearing the control hydration bags on their backs during the entire test, five of them (8.9%) reported that they left their hydration bags hanging on trucks, carried them, or left them in the shade because the water became unpalatably warm when worn on their backs. However, not one Marine chose to leave either chiller hydration bag hanging from a truck or in the shade due to an unpalatable increase in warmth of water. One

participant reported utilizing the adaptor to relocate the battery-powered chiller away from the cap to achieve easier refilling of water, but all of the others using the battery-powered chillers and all of those using the non-powered chillers reported wearing them on their backs for the entire test. Not only does this indicate that both water chillers were keeping the water significantly cooler than the control system, but with water systems still attached to their backs, they had increased ease of access to cool water.

7 PARTICIPANT COMMENTS

All of the bullets in this section are quotations from the Marines. They are separated into sections on *why* the respondents preferred the control system, the battery-powered water chiller, or the non-powered water chiller and on *what* the Marines *liked/disliked* about each water chiller

7.1 BATTERY-POWERED WATER CHILLER PREFERENCE

- The non-powered was too hard to suck through and with an in country filter on it, it will be even harder.
- It kept the water cooler.
- Because it was easy to use and it kept the water cold.
- I think that one would work until the battery dies.
- Because with the non-power chiller I'm just wasting water.
- Because it cools water more and it has a lot more capabilities than the other 2 and the hose extends more.

7.2 NON-POWERED WATER CHILLER PREFERENCE

- I like the non-powered water chiller the best because it takes no batteries and it keeps the water cooler. It could probably last longer as well.
- It was the only one that provided chilled water while you were drinking for more than one sip.
- The water was cooler.
- The non-powered water chiller was easier to use and more durable.
- The non-powered chiller cooled more water for a longer period of time rather than the battery-powered
- Easy to use and it was the only one to cool the water down.
- It cooled the water the best and fastest.
- The water was constantly cooler than the Camelbacks.
- Besides being a little too bulky, it wasn't noisy and complicated. It also kept the water cold.
- It kept the water the coldest and didn't break on me.
- More gear requiring batteries is an issue.
- It was very easy and efficient in the long run. It kept my h2o very cool and in the end I don't have to worry about batteries.
- It simply did its job the best. I left it in my vehicle all day. This vehicle will melt CD cases from the heat inside, but after flushing the hose the water was still cold.
- It kept all of the water cooler rather than just a small portion at a time.

- It worked!! The battery powered one is too frail and broke too easily. And the non-powered worked all the time.
- The non-powered water chiller cooled the water more effectively than the battery powered water chiller.
- Kept water much cooler than the rest. No mechanical problems.
- It was cooler, a little bulky but still served its service, plus makes a nice pillow.
- Simpler to use and still provided cooler water.
- I felt the water temperature was cooler.

7.3 WATER CHILLER CO-PREFERENCE

- Both had pros and cons. They both however need to be more durable and less bulky. Good idea just needs some work.

7.4 CONTROL HYDRATION SYSTEM PREFERENCE

- You are able to drink water more easily, if I want cold water I can add ice and not have to deal with extra stuff breaking.
- Easier to drink from, non-powered was hard to drink from harder to maneuver with trucks, with neither water chiller there is extra space so can maneuver into and out of trucks.

7.5 LIKES/DISLIKES FOR BATTERY-POWERED WATER CHILLER

- Only small portions of water would be cool, not the entire camelback.
- It was cold and worked. Batteries are not always around.
- The tubing web seems more durable. I don't think the fan would be durable enough in combat zone.
- The thing I don't like about the battery powered was the blades broke easily and batteries don't last long.
- What happens if the battery dies and you have no more battery.
- I disliked the fact that the fan broke so easily.
- I did not like how the fan shut off on its own. I also did not like how the hose is too long. I like the capabilities.
- I liked that it cooled down a gulp of water or so but I did not like how fragile it was.
- The only positive is that it actually cooled it for about one sip. It is annoying and can detach too easily along with how easily the fan can break. Along with a short battery life.
- It was fragile and it made a lot of noise.
- It kept the water cool for a short time. Easily broke and fan was loud.

- I disliked the noise and the consistent buzz from fan. I disliked that it only cooled a little bit of the water that was in the tube.
- Fan stopped working. Dust got inside the fan too easily. Hard to get any water out.
- It was too fragile but it did work as fast as cooling the water. A little bulky and fell off often.
- The camelback can break easily. The water was not constantly cool.
- It was too noisy and complicated.
- It broke after about an hour. It is too noisy.
- Utilizing the device is problematic if continually switching from ruck on ruck off. Anything with batteries and moving parts (fan) is prone to break.
- I did not like it because it did not operate properly and died about 5 hours into use. Also the chips kept losing grip.
- I liked how small the design was but the reliability was a big issue. Batteries can die, fan blades brake, motors burn out etc. It didn't even cool all that well.
- It was too fragile, the battery did not last very long and it only cooled small amounts of water at a time. Had to re-prime multiple times.
- Batteries don't last, breaks too easy, hard to get water out.
- Only cooled the water briefly.
- Only gave one cold blast of water. Then had battery issues (going dead).
- Batteries cost too much for units, too many moving parts, too easy to break or lose parts
- It was harder to get water from the reservoir to my mouth. It could be because the tubing was longer. I would prefer something that does not require batteries to operate.
- The extended hose can potentially get in the way of gear being worn
- Too bulky and fragile. Good at cooling.
- It broke too easily, not enough water was dispensed, if you ran out of batteries it pretty much is useless.
- Liked the design/idea. It was a little too bulky, broke easy, liked the mouth piece.

7.6 LIKES/DISLIKES FOR NON-POWERED WATER CHILLER

- Like the quick release switch for the mouth piece.
- Too hard to suck through. It was cold.
- It is way too big, not comfortable to wear.
- The only thing was that it is too bulky.
- Really can’t use it everywhere.
- I disliked t the fact that the filter was too big.
- The water gets a lot colder, I liked but I did not like, it's too big.
- I liked that it kept the water cooler and that it didn’t have batteries. I did not like how the cooler itself was placed so high up that it would hit the back of your head.

- It provided a steady amount of chilled water and was easier to use. A little bulky but it makes up in its ability to chill water.
- It was bulky and it hit the back of my head.
- Kept the water cool at all times. Very durable and stylish.
- I liked that it kept the water cool and I wanted to drink out of it. I liked that it was easy to use and i did not have to take it apart to put water in it.
- Cooled down the water but at times was hard to get water out and was too bulky.
- It was a little bulky and caught on stuff in/out of HUMVEE but worked very well and required zero maintenance.
- The water was cooler most of the time. The camelback is uncomfortable to wear.
- It was too bulky. However it kept the water cold and it was easy to use.
- It works well, it didn't break. It looks kinda ridiculous. It would be better if attached to a lower part of the pack.
- Like the idea but device is too large. Maybe a device in-line may not be as effective but would be more usable in the tactical environment.
- Very simple and kept my water very cool and I had no issues.
- I liked this cooler the most. The water was always chilled. Easy to use. It is also very reliable. The only downsides are its bulkiness, and it was somewhat difficult to pull water through the hose.
- I liked its effectiveness in cooling the water, easy to clean and durable.
- It's a normal camelback w/ no chiller so it got hot pretty easy.
- It was hard to get the water through the tube.
- Design of the compartment (too bulky). Difficulty to suck water. (not a show stopper).
- Kept water cool, too bulky, nice pillow, liked side pocket.
- This was simple to use and the water was noticeably cooler than a normal camelback.
- Easy to manipulate, very convenient, needed.
- Too bulky and fragile. Good at cooling. If you double the size of the Camelback so it covers the back entirely and then make the cooler (either or) more "inside" the Camelback but outside the bladder it will increase the durability and size. This has great
- It cooled the water but it broke too easily. It was also difficult to get water out of it and was time consuming to drink water.
- I think it kept the water the coolest, was hard to get water out of the tube. Great idea if there was a better way for the water to come out smoother.

8 CONCLUSIONS

Figure 2 compares the Marines' satisfaction/dissatisfaction with the three systems tested.Figure compares the Marines' perception of the temperature of the water from the three systems. Figure 4 compares the Marines' estimates of the number of full hydration bags of water they drank from each system. The majority of the Marines perceived the chilled water to be significantly colder, were satisfied with the water temperature that the beverage chillers produced, and were satisfied with the overall concept of using a beverage chiller. Most (85.5%) of the participants were satisfied to some degree with the non-powered chiller, with 14% of them reporting that they were extremely satisfied, while 63.5% were satisfied with the powered chiller. Only 14.3% were satisfied with the control system. Likewise, 75% of the Marines reported that the control water was too warm. On the other hand, 73% felt that the powered chiller produced cold water, and 94% perceived the water from the non-powered to be cold.

The participants also reported drinking more water when using a beverage chiller.

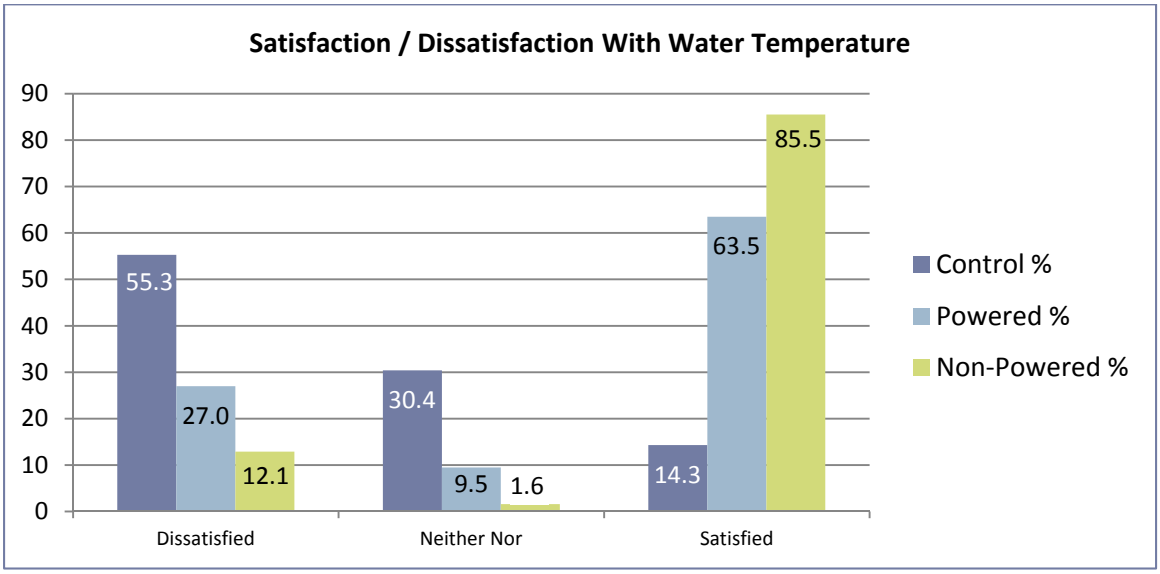

Figure 2: Water Temperature Satisfaction for Each Test System

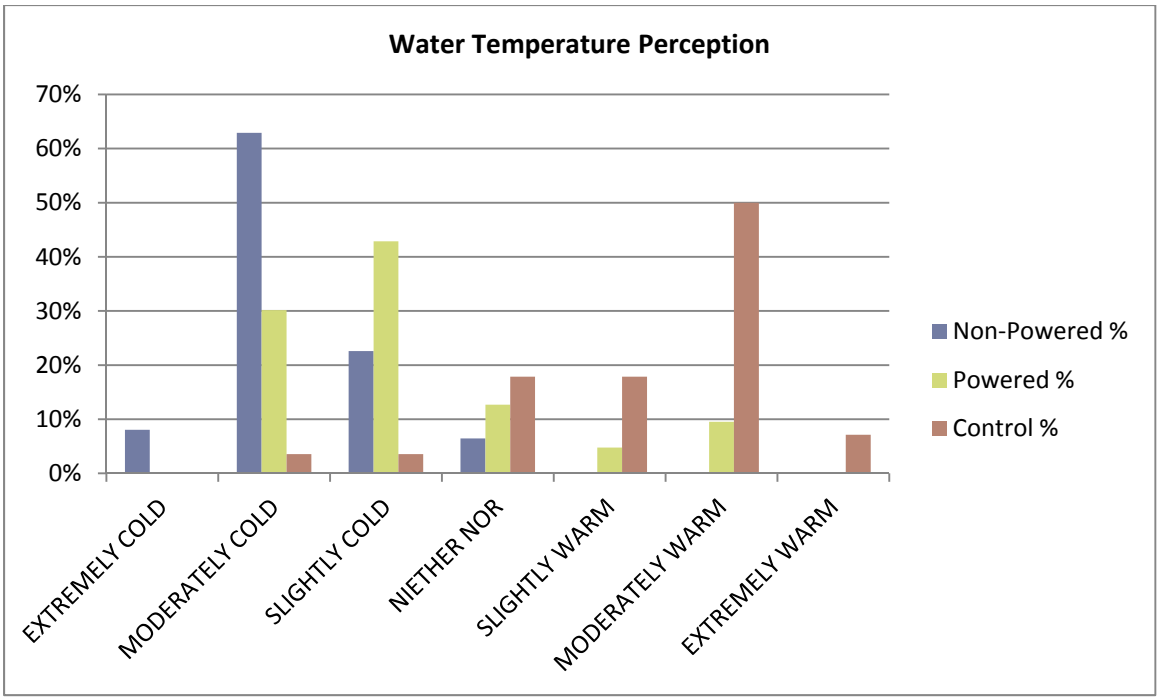

Figure 3: Water Temperature Perception

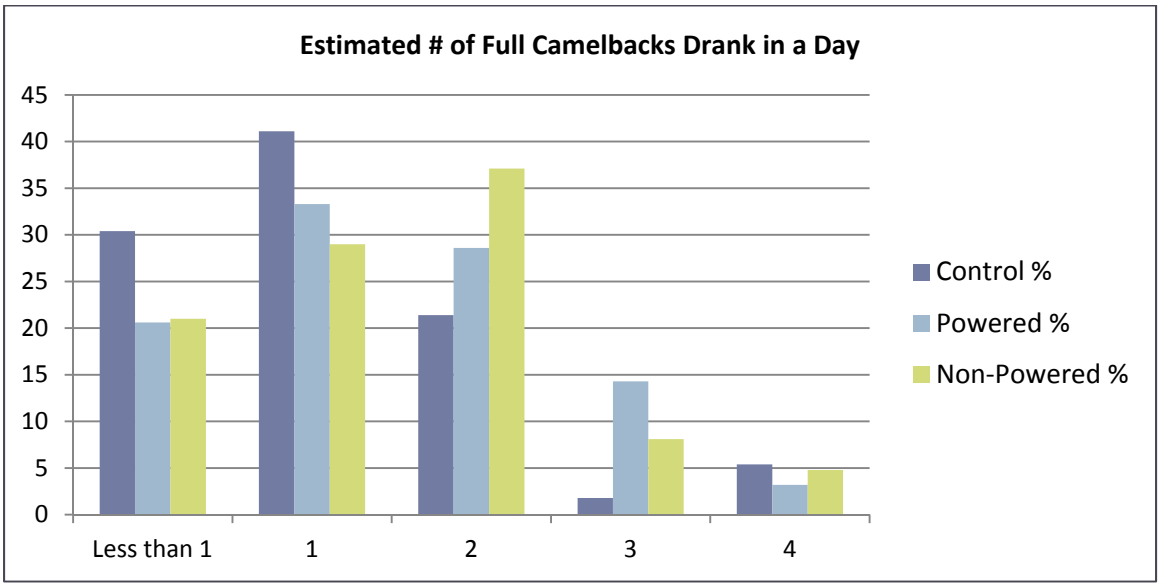

Figure 4: Estimated Daily Water Consumption

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 12/026 in a series of reports approved for publication.

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